

# Overview of insertion device controls at the Advanced Photon Source

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The Advanced Photon Source (APS) is a third-generation synchrotron with major emphasis on insertion device (ID) sources. Currently, there are 25 sectors instrumented out of a possible 35 ID sources. Most of the insertion devices are undulators. Beamlines have been using the ID radiation at the APS for more than five years. The control system of choice at the APS is the experimental physics and industrial control system (EPICS) (<http://www.aps.anl.gov/epics>). Based on operational experience, the ID control system has been completely revamped. During user operations, the beamline user has complete control of the insertion device. Various interfaces, from RS-232 to EPICS channel access, have been provided for the users to control the IDs. The control system software has been designed to accommodate scanning of the insertion device synchronized to each user's beamline monochromator. The users have the option of operating the device in a tapered mode. The control software allows the users to control the undulators in energy space from the fundamental to the seventh harmonic. The design philosophy of the insertion device control system will be discussed. The implementation and operational experience will be presented in detail.

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## I. INTRODUCTION

The insertion devices (IDs) at the Advanced Photon Source (APS) have been in operation for more than five years. The ID control system<sup>1</sup> has been experimental physics and industrial control system (EPICS) based since the start of operation. Based on our operational experience,<sup>2</sup> we felt the need for better control of the device, with greater diagnostic capability. To achieve these additional requirements, the software and hardware for the ID control system have been completely redesigned.

## II. HARDWARE

STI Optronics manufactured the IDs to APS specifications. Most of the devices are 2.4 m in length. The two jaws, upper and lower, are mechanically coupled at the two ends of the device. The drive mechanism consists of stepping motors attached to gearboxes and mechanically linked by chains to the Cone Drive worm gear reducers attached to each jaw. The drive mechanisms are located about 0.55 m from the ends of the device. There are two absolute rotary encoders and two absolute linear encoders on the device. The rotary encoders are attached to Cone Drives on the top jaw at either end. The linear encoder is attached to the top and bottom jaw at about 0.15 m from each end of the device. The linear encoder measures the absolute gap between the two jaws, at the upstream and downstream ends of the device. Each end of each jaw has one maximum gap limit switch and two minimum gap limit switches. The device has four mechanical hard stops, one for each end of each jaw to stop the two jaws from touching each other or the vacuum chamber. The device also has an emergency stop mushroom button. There

are two potentiometers mounted at either end to measure the gap independently of the control system. The control system consists of a VME crate with a Motorola MVME-167 processor. The VME crate is loaded with an eight-axis Oregon Micro Systems VME-8 motor controller, a VAROC board (developed by the European Synchrotron Radiation Facility) for reading the SSI-based absolute encoders, and an ID control VME interface board developed by APS.<sup>3</sup> The motor controller in turn is interfaced to a Superior Electric drive. All the limit switches and the emergency stop from the device are routed through the ID control VME interface board. The control system hardware layout is shown in Fig. 1.

## III. DESIGN PHILOSOPHY

The ID control system has to be flexible for different operations and at the same time be robust and reliable. The control system has to be transparent to the users and to accelerator operation. For seamless integration into the accelerator control system, the control software of choice was EPICS. The user needs dictate the design of the software. Due to the diverse nature of the user community, the choice of software used in the beamlines is vast. The ID control system had to provide other means of control besides through EPICS. The popular choice was RS-232 serial communications between the control system and the user computer. The users relate to the device in terms of the energy of the x-ray beam produced by it. The software has to convert this energy input into physical gaps, and the device has to be positioned precisely to produce the required x-ray beam energy for the chosen harmonic.

The APS operates by interleaving user operations with machine studies. During user operation, once the storage ring delivers the beam, the users have full control of the device. During machine studies, the machine physicists have control.

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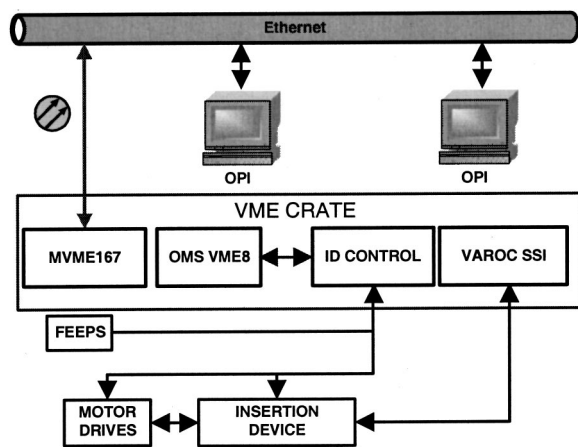


FIG. 1. Hardware layout of the ID control system.

#### IV. SOFTWARE

The ID control system is based on EPICS. The MV167 processor in the VME crate operates under the VXWORKS operating system and acts as the input/output controller (IOC). The processor is connected via Ethernet to the controls network. The operator interface (OPI) part of EPICS is based on either the UNIX or PC platform. The new implementation of the software is all based on EPICS database records. The software is modular in nature. Based on functional requirements, different parts of the software operate independently. All key activities are logged in a data file on the file servers. The device is operated in an open loop with the encoders providing the feedback to all motion. Due to the design of the device, the motion at either end is coupled to the other end. The software flow chart is shown in Fig. 2.

The user interacts with the control system with use of a few EPICS process variables (PVs). The user has the ability to operate the device either in terms of the physical end gap or in terms of the energy of the x-ray beam produced by the device. The user also has the ability to broaden the band-

width of the x rays produced.<sup>4</sup> This is achieved by tapering the device with one end at a different gap than the other end.

The ID magnetic fields are measured at the APS magnetic measurement facility.<sup>5</sup> The magnetic data as a function of the gap between the jaws is used to determine the energy produced by the device. The energy-gap conversion is possible in the case of the undulators from the fundamental to the seventh harmonic. The calculations take into account the finite beam size.<sup>6</sup> The magnetic data as a function of the gap are loaded into the IOC processor memory at initialization. Subsequently, EPICS subroutine records access the calculations to convert between gap and the energy/harmonic combinations.

All user inputs are handled by one module. Users have the option of selecting the energy with the required harmonic for the undulator devices. They can also select the energy spread required for specific experiments. Instead of selecting in terms of energy, one can directly select the desired gap of the device. The software converts the data from energy to gap and vice versa. After conversion the gap value is checked against the operating parameters of the specific device. If the values are within the operating parameters, the values are accepted, a message is displayed to the user, and the values are recorded in a log file.

All readbacks are handled by one module. The motor controller is interrupt driven. The motors are calibrated to read the gap in user units directly. All the encoders are processed sequentially at a 10 Hz rate. Based on the choice of encoder, the gap at the ends of the device is calculated. In addition, the gap at the location of the motor is also calculated for comparison with the motor readbacks. With the knowledge of the end gap, the average gap and the amount of the taper are determined. In addition, based on the user-selected harmonic value, the energy of the beam produced by the device is also displayed. The gap-energy conversion is accomplished with subroutine records to access the conversion calculations.

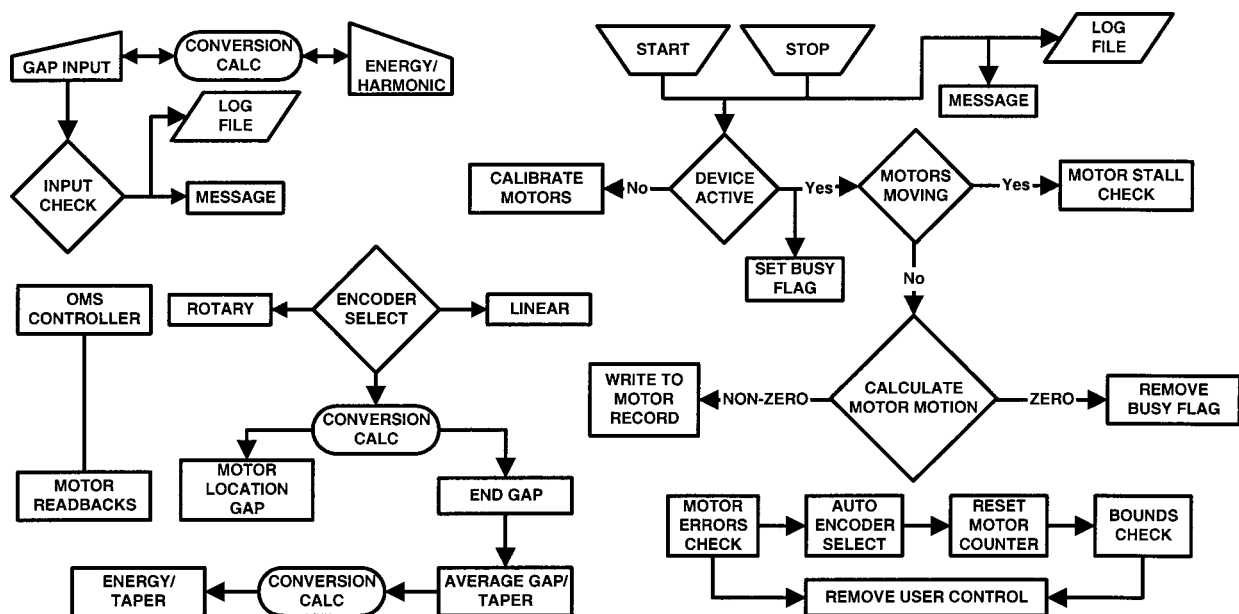


FIG. 2. Software flow chart of the ID control system.

When the device is commanded for action, two PVs are triggered. One indicates to the user that the device is busy moving. The other is used internally between the various database records to sequence the order of actions to be taken. Due to cross coupling between the two drive locations and to avoid overshooting the desired location, a pseudo-PID loop is used. Based on the desired destination, the amount of motion at the drive location is determined and a percentage of it is applied to the motor records. Once the motor record indicates a completion of the move, the above-mentioned loop is repeated to determine the amount to move. Once the convergence is reached within the operating accuracy of the device, the user motion is stopped and the device busy flag is removed.

One module performs checks at 0.5 s intervals to make sure that the device is operating properly. One database record checks the gaps of the device to make sure that they are within the operating parameters. If by some means either gap is outside the operating parameters, the device is stopped and access to the device control is removed for everyone but the system manager. Another database record checks to make sure that the motor readbacks are calibrated. If they lose calibration due to motor stalls, this record will calibrate the motor readbacks to be the same as the encoder feedbacks. The health of all the encoders is periodically checked. Automatic switching of the calculation for device gap is performed between the rotary and linear encoders. The presence of a large magnetic force between the two jaws at small gaps causes the drive screws to stretch by as much as 200  $\mu\text{m}$  between gaps of 11 and 25 mm. Due to the screw stretching effect, the linear encoders are the preferred mode of feedback over the rotary encoders. Detection of a limit switch being hit will automatically remove all control of the device from the users. If the device is determined by the above-mentioned checks to be beyond the normal operating conditions, the access of the device is switched to system manager mode. The system manager has access to all database records at all times. The device condition can be assessed using the EPICS MEDM OPI.

During beam studies, the accelerator operators have full control of all the devices and can open and close all devices with one command. This feature is used when all the gaps are opened for injection. Following injection, the operator commands the device to close, which in turn gives access of the device to the users and returns all devices to the previous user-desired gaps.

There is great desire in the user community to collect data while moving the undulator. The user has to synchronize the beamline optics monochromator with the undulator energy to perform these scans. In order to accomplish this the user can select the starting gap, ending gap, and the time to cover the distance. Based on these inputs the device is moved to a gap outside the range. Once it has attained the required scan rate and it reaches the targeted starting gap, the control system signals the user of the scanning action. Upon reaching the targeted end gap the signal is turned off.

Users can control the device in one of two ways. The most common method has been through the use of EPICS channel access. Due to network security, the communication between the IOC operating the device and the users network is through a PV gateway.<sup>7</sup> A direct serial link between the IOC and the user beamline is through fiber-optic cable for control of the device. Control is achieved by sending simple ASCII commands; querying with simple ASCII commands can also monitor the status of the device.

## V. CONCLUSION

The new control system has been introduced into operation in phases. Parts of the control system were put in place as of January 2001. The complete system has been commissioned for all the devices since July 2001. The transformation from the old control system to the new has been transparent to the users. Work is in progress to further enhance the capabilities of the new control system.

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